A REAL-TIME ULTRASONIC IMAGING SYSTEM (ARIS) FOR MANUAL INSPECTION OF AIRCRAFT COMPOSITE STRUCTURES

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INTRODUCTION

Inspection of aircraft composite structures at field site facilities (air bases) is routinely performed using manual ultrasonic testing (UT) techniques. Using these techniques, the examiner detects and sizes defects such as disbonds and delaminations by monitoring and interpreting A-scan waveform signals on a UT instrument display screen. Manual probe manipulation permits maximum scanning flexibility and optimization of the ultrasonic signal response by the examiner using manual motions not possible with mechanized scanners. However, the examiner also must be responsible for instrument calibration, signal interpretation, documentation of inspection results, and completeness of coverage. The data reviewer must be able to validate instrument calibration and completeness of coverage, confirm signal interpretation, and compare current UT results to those obtained during previous inspections.

Considerable effort has been expended over the last eight years to develop an inspection system for aircraft composite and bonded structures to provide manual scanning simultaneously with automatic recording of UT and probe-location data. The final goal of such an effort was to establish a system that (1) was compatible with current manual inspection procedures, (2) recorded parameter and inspection data and produced images similar to those obtained during production testing, and (3) increased inspection quality by providing real-time scan coverage and processed-data displays for the examiner while generating a comprehensive documentation record for the data reviewer. One primary advantage of having such a system was the availability of permanently recorded data presentations that could be used to identify changes in flaw configuration and size over a period of aircraft operation. Within the past three years an Air Force funded program (USAF contract number F33615-83-C-5066) permitted development of an inservice inspection system providing all of the itemized capabilities resulting in production of the Automated Real-Time Imaging System (ARIS).

OBJECTIVES

The ARIS technology is based on the principle of simultaneously recording UT data along with the ultrasonic search unit position during a manually scanned inspection; the position is determined using an acoustic triangulation approach. The current production ARIS technology addresses the needs of both the examiner and the data reviewer: simplicity of setup; ease of calibration (downloading of prerecorded parameters); real-time display of coverage and processed data to improve inspection quality; flexibility and portability; and complete documentation of all calibration parameters, coverage, and processed data results. With automated data collection features, the system must collect, store, process, recall, and display large amounts of data conveniently. Convenient use of data is the key ARIS technical benefit. ARIS images acquired during different stages of aircraft life can be compared with each other and with production images to monitor flaw initiation and growth.

The principal objectives of the technical approach were to develop:

(1) A transportable system based on modular assemblies ruggedized for shipment as airline luggage while also providing convenient assembly and setup.

(2) A high productivity system with features such as:

   (a) An electronic template for defining component inspection boundaries to guide the operator in manipulating the probe assembly while defining completeness of coverage and processed data results in real-time.

   (b) Simplified operational software based on the use of high-level commands of a type familiar to the average inspector.

   (c) Remote display and control capability for convenient inspection system interaction.

   (d) An adaptable search-unit assembly, configured for use with standard transducer types and ergonomically engineered to greatly reduce examiner fatigue.

   (e) Archival storage of all parameter (including instrument calibration) and inspection data to facilitate post-examination retrieval and review.

(3) An affordable and producible system based for the most part on commercially available components.

(4) A flexible system with features such as:

   (a) Processor-controllable ultrasonic instrument compatible with inspection requirements of advanced composite and bonded structures.

   (b) Modular position-locating assembly.

   (c) Modular software adaptable to existing flaw detection and characterization methods.

SYSTEM DISCUSSION

The completed ARIS consists of the components shown in Figure 1. All components (including the mobile cart) are designed to be conveniently transportable and are mounted in ruggedized enclosures which can be shipped as airline luggage. The system can be quickly and easily assembled at the inspection site (no tools are required) and is designed for use by one examiner to facilitate inspection of components which are remote from the control unit (see Figure 1).

System control is accomplished using dual microprocessors and a programmable read-only memory (PROM) based software package. The control software is menu driven and permits operator activation of four major modules, as shown in the structural hierarchy of Figure 2. These modules provide the following functional capabilities:

- System checkout module permits the operator to test proper operation of each system component. Selected components can be operated independently and readouts accessed to determine component operational status.

- Parameter generation module allows the operator to generate operator parameters, UT instrument calibration parameters, and inspection template data and to store this information on diskette for subsequent recall.

- Acquisition module permits data acquisition and real-time processing and display. Three modes of operation are supported. Inspection data can be stored on diskette for subsequent analysis.

- Post-processing module allows data-review and analysis functions using previously stored examination data.

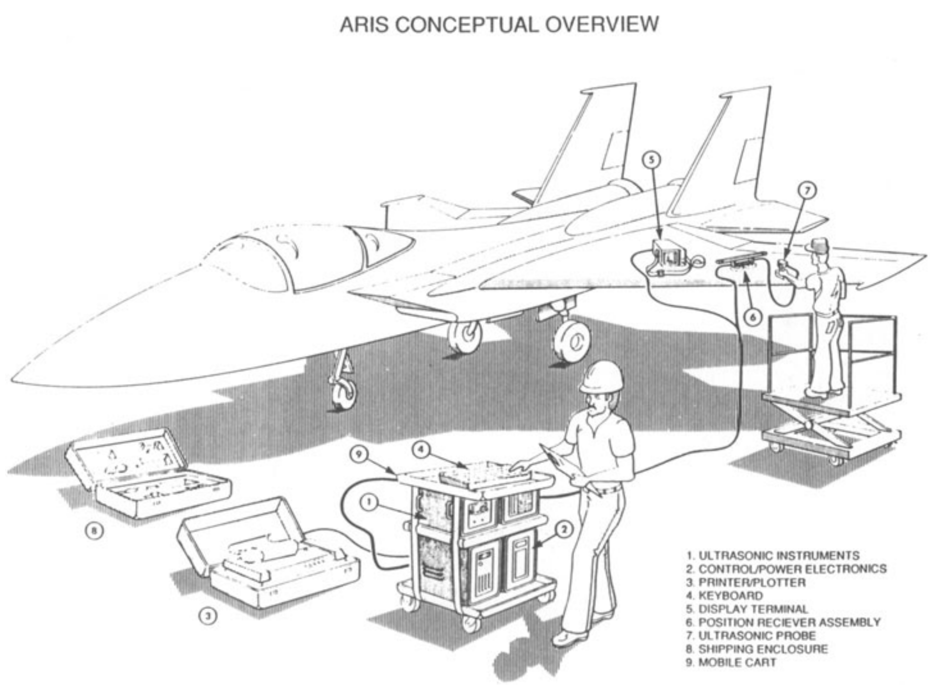

Fig. 1. Conceptual drawing of system hardware configured for remote inspection operation.

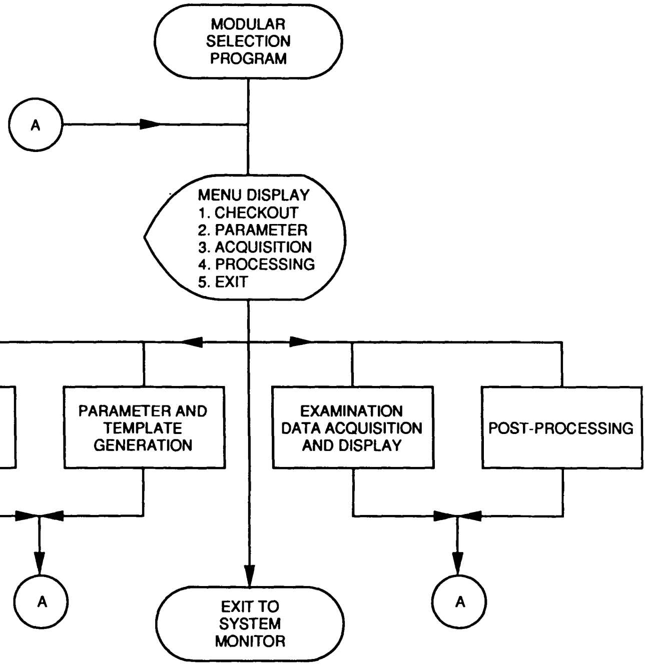

Fig. 2. Operator menu hierarchy

The operator controls the system by activating selected functional capabilities using a hierarchy of control menus. For each menu displayed, the operator is presented with a limited set of options corresponding to the type of function being performed. In each menu, selections are presented using easily understood language. The keyboard control key associated with any option can be easily deduced by noting the option number presented on the menu list. The menu hierarchy can be traversed in both directions and provides an orderly sequence by which to schedule and control activities.

To initiate an examination, the operator can recall all inspection parameters from diskette. These include the UT instrument calibration parameters and the inspection region electronic template data. The electronic template defines areas on the component surface (up to 4 x 4 feet) requiring examination and guides the operator in manipulating the inspection probe. The template is oriented to the aircraft component using predefined target points (landmarks such as rivets and fasteners). The operator procedurally defines target points permitting computer display of the electronic template on the screen. Remote inspections can be performed by utilizing a camera mounted in front of the UT instrument screen to transmit the A-scan display to the monitor. The keypad allows the operator to select either the A-scan camera display or real-time coverage/template display for presentation on the monitor. The UT instrument (KB-USD1) can also be controlled remotely using the keypad.

During an examination, the coverage/template display is updated in real-time to demonstrate coverage corresponding to operator manipulation of the transducer over the inspected region. A cursor is displayed on the screen to show the operator where the transducer is located in respect to the template-defined inspection boundary. In addition to inspection coverage information, two types of real-time ultrasonic data processing are provided. The operator may perform GO/NO-GO (threshold level) processing using either positive or negative threshold violation or color-scale processing (16 levels) using time, depth, or amplitude data. Examinations can be performed using pulse-echo or through-transmission UT inspection techniques. Data can be analyzed during the examination by pausing the real-time processing. The inspection data can be hardcopied (scaled or 1:1) and stored on diskette for subsequent recall and additional analysis. Post-processing functions permit the operator to perform a detailed evaluation of the data, including the capability to locate indications of interest on the actual component surface using either a 1:1 map overlay technique or a triangulation technique using predefined target-point locations and arc lengths as defined on a tabular printout.

The system incorporates specially designed inspection probe devices to facilitate assembly and changeout of components (such as search units, delay tips, and boot assembly). No tools are required for assembly or disassembly. A stylus/holder assembly (as shown in Figure 3) allows the operator to manipulate the transducer by hand and is ergonomically engineered to reduce operator fatigue. When performing inspections on component surfaces that are oriented awkwardly (component underside or highly angulated component surfaces) and rapidly induce operator fatigue if scanned using hand manipulation, the stylus/holder can be mounted in the scan-probe pole or yoke-assembly units, as shown in Figures 4 and 5. The yoke assembly can also accommodate a boot attachment providing excellent surface compliance and facilitating through-transmission inspections. The yoke arms are spring loaded and incorporate gimbaled mounts for the transducer holder. The sound bar (receiver) unit can be mounted using adjustable vacuum cups or a tripod assembly.

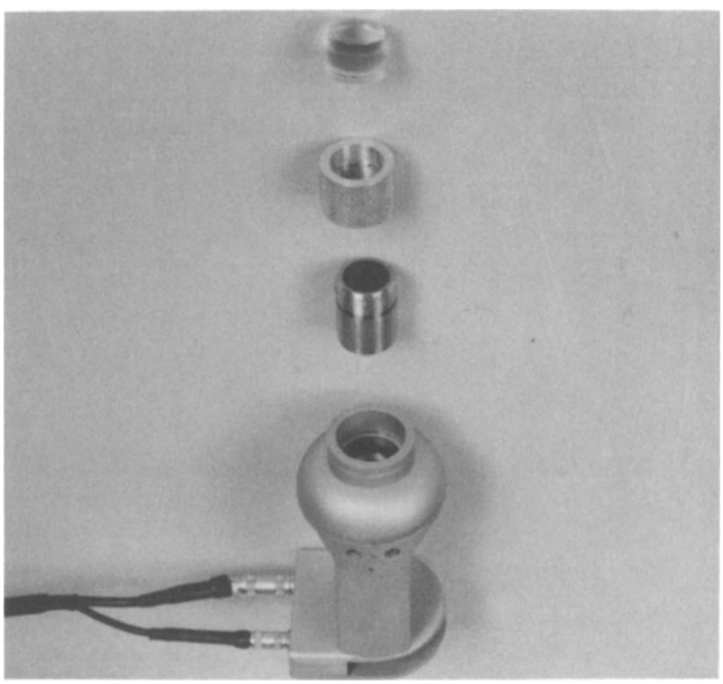

Fig. 3. Stylus/holder assembly

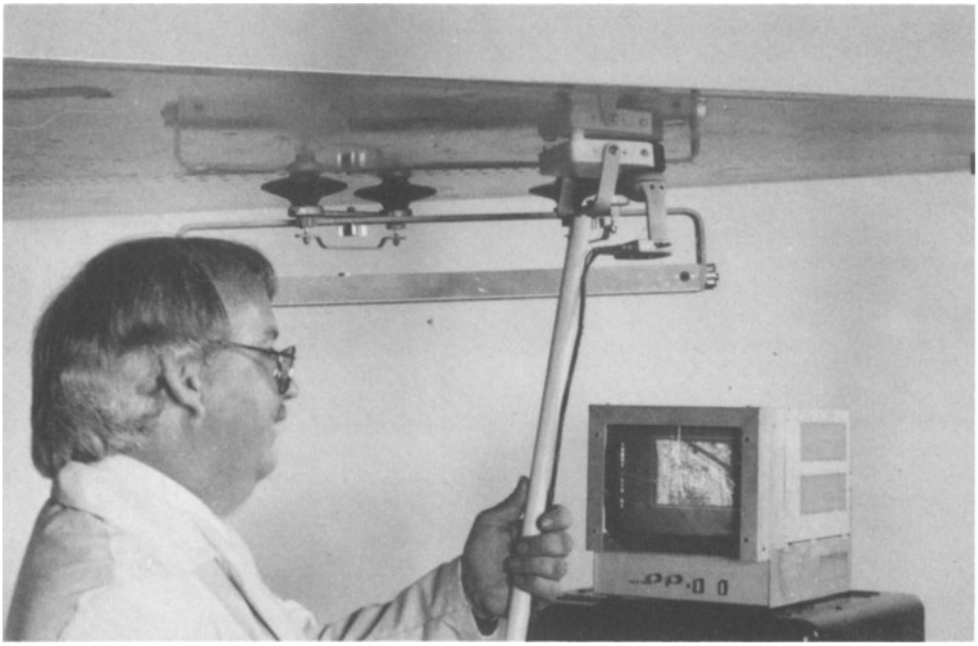

Fig. 4. ARIS photo of scan-probe pole. Note that the examiner's hands and wrists are in a comfortable position and arms are at a comfortable height.

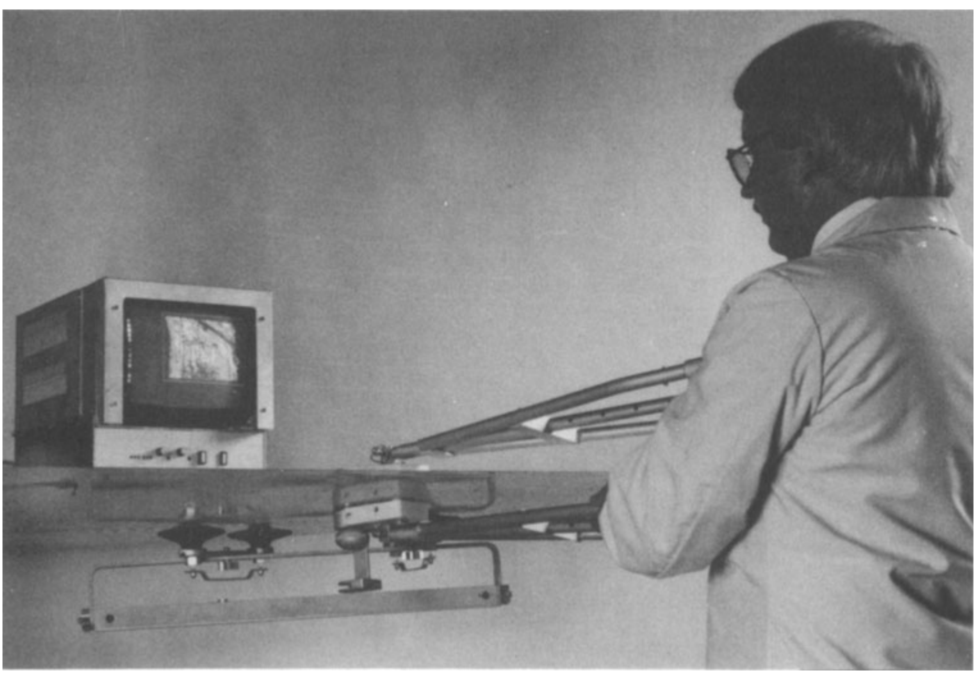

Fig. 5. ARIS yoke assembly facilitating through-transmission examinations or pulse-echo examinations of awkwardly oriented component surfaces.

SYSTEM VALIDATION

System operation was validated using the test plate depicted in Figure 6. This plate contains a series of bottom-drilled holes varying in size (0.25 to 2.125 inches) and depth (0.10 to 0.40 inch). An ARIS display of this plate is shown in Figure 7 and represents a C-scan presentation in which depth in material is shown using color modulation. The C-scan display area is represented using a collection of 0.111 inch-square elements (pixels), which account for the step-shape boundaries of each hole. The color scale on the left side of the figure defines the color versus depth relationship.

The initial (preproduction) ARIS was evaluated at five Air Force bases (Edwards, Randolph, Hill, Charleston, and Wright-Patterson). Testing and evaluation were primarily performed by a third party (Universal Technology Corporation) contracted by the Air Force to determine if satisfactory performance was achieved and to provide recommendations for improvements to be subsequently incorporated in the production models. The system was used to examine various components on the following aircraft: X-29, B-1B, F-S, F-15, F-18, T-38, and C-141. Both pulse-echo and through-transmission inspections were performed. Special emphasis was placed on examining aircraft components with awkward orientations to test the special features of ARIS for performing such examinations.

Figure 8 shows examination data obtained from a portion of the highly tapered composite wing on the X-29 and generated during a 5-MHz, pulse-echo inspection conducted at Edwards AFB. Figure 9 shows data obtained from a portion of the aluminum honeycomb structure of a T-38 horizontal and generated during a 1-MHz, through-transmission inspection conducted at Randolph AFB.

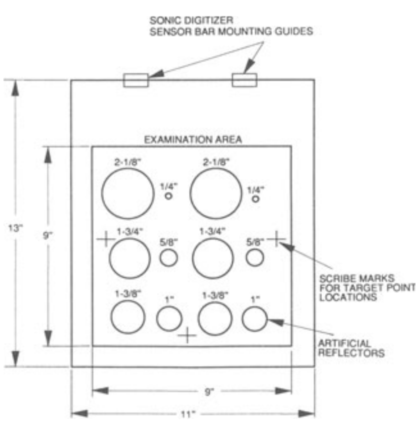

Fig. 6. ARIS test-plate hole pattern. Hole diameters vary as shown while the depths are mirrored (reversed) about the vertical centerline.

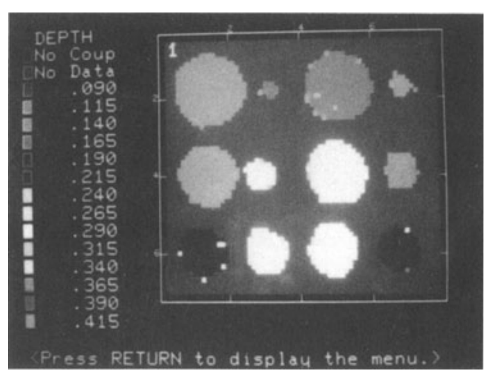

Fig. 7. ARIS pulse-echo test-plate examination results using a C-Scan presentation in which color represents hole depth within the material.

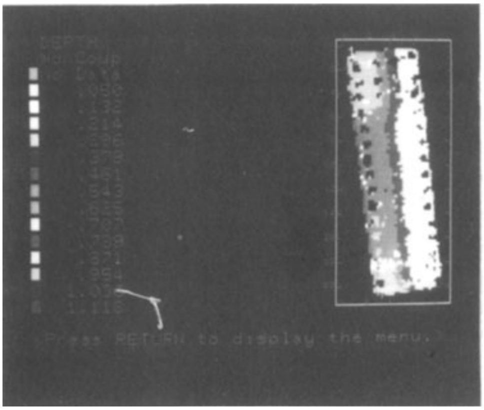

Fig. 8. ARIS pulse-echo examination results of a carbon-epoxy region from an X-29 wing. The dark-colored holes in the image pattern represent fastener locations.

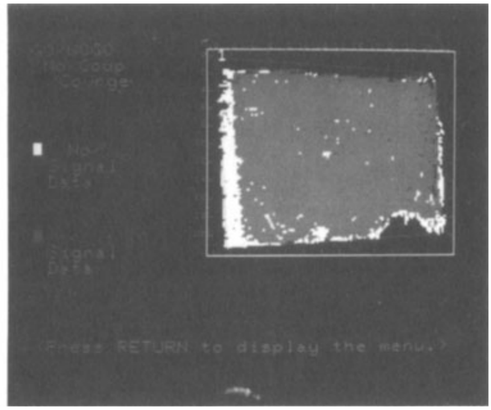

Fig. 9. ARIS through-transmission examination results of a T-38 horizontal stabilator consisting of an aluminum skin bonded to a honeycomb core. The circular pattern feature is a foam-patch repair area.

CONCLUSION

ARIS was designed to permit routine day-to-day examinations of aircraft composite structures using established manual UT techniques while providing automated data recording, processing, and analysis functions. The system provides real-time coverage and processed data displays, thus permitting higher quality examinations while providing comprehensive documentation to permit more effective data review. The system has successfully completed a series of field site evaluations and is currently in production with deliveries scheduled for Fall 1987.